APPENDIX A
TECHNOLOGY OVERVIEW

INCIDENT DETECTION AND MANAGEMENT TECHNOLOGY OVERVIEW

The heart of an incident detection and management program is the surveillance sub-system. This sub-system supports three different types of functions: counting and monitoring individual vehicles; analyzing vehicle flow information for incident and subsequent congestion detection; and providing visual images for confirmation, interpretation and analysis.

Incident detection and management relies on accurate real-time traffic flow data. In order to obtain this data, a detection system is needed. A hybrid system of automated detection systems, using computers monitoring detector locations, and systems that rely on a human observer using closed circuit television is the configuration most commonly used by other traffic management systems in the U.S. Although each sub-system can work independently, automated detection and visual verification are functions that complement one another. The best performance results from an automated detection system that calls upon a human observer to view a possible incident and determine an appropriate response. As more progress is made in IVHS technologies, such as image processing, artificial intelligence, and expert systems technology, it is inevitable that computer systems will augment the capabilities of the human observer.

The transmittal of information to the motorist is the feedback component of an incident management system. This provides the mechanism to alert the motorist of problems ahead, so that an alternate route can be taken. The most commonly used technology installed along the road is the Variable Message Sign (VMS). Another commonly used device is the Highway Advisory Radio (HAR). The use of dial-in telephone services has been implemented in various forms, and the term Highway Advisory Telephone (HAT) is coming into common usage. Commercial radio and television stations broadcast traffic reports in many metropolitan areas, and studies have shown that this is the most commonly used source of traffic information.

The computer equipment and software located at the traffic operations center (TOC) collects and centralizes all the various data and information that is generated by the surveillance sub-system. It also provides the control interface for the motorist information sub-systems. Modem computer technology has reduced the size and cost of the computer hardware. However, the complexity of the software continues to increase as the functional demands for graphical user interfaces, and other state-of-the-art features, are included in the overall computer system.

VEHICLE DETECTION

Vehicle detection technologies form the foundation of the surveillance sub-system used for automated incident detection and traffic management. The surveillance information provided by vehicle detection enables the collection of a range of traffic data including speed, volume, density, travel time, and in some cases, vehicle position. Control strategies, incident management procedures, and motorist information displays are selected based upon the data collected by the vehicle detection system. The collected data is used in real-time for making traffic management decisions and stored to provide a historical data-base of traffic conditions.

Surveillance can also be used to obtain information on vehicle classification, length, speed, acceleration characteristics, and hazardous materials.

Operational environment and maintenance requirements are two of the most critical factors in determining the types of detectors for the system. Systems that involve retrofitting existing road surfaces and pavement structures (such as induction loops) can create installation and maintenance problems. Technologies that do not require these modifications are termed non-instrusive installations, and minimize the traffic diversion and control problems.

Secondly, the choice of detectors for an automated system is dependent on the data requirements. To meet the needs of the recommended ultimate I-65 system, real-time data to ascertain vehicle speed, counts, lane occupancy, classification, and changes in motion and position, will be required for automated incident detection. In addition, the real-time data, once obtained, needs to be stored for historical as well as planning use for potential system expansion. The overriding concern with the latter relate to data collection requirements for future facility planning, as defined by ISTEA.

There are two separate approaches to vehicle detection - those that are passive and involve no electronics in the vehicle, and those that cooperatively utilize electronics in the vehicle and alongside the road. As with all areas of electronic technologies, changes occur regularly - providing new solutions to existing problems, but conversely requiring that systems be flexible enough to accommodate change on a regular basis.

The technologies that are applicable to this project are discussed below. There are numerous other technologies that have been experimented with and tested by various departments of transportation and the FHWA. In particular, the current "Detection Technology for IVHS" project sponsored by FHWA is evaluating a wide range of equipment under laboratory and field conditions. Although many of these technologies show promise, they have not progressed to reliable field operation. In order to limit system complexity, and resultant operations and maintenance costs, minimizing the number of different technologies is preferred.

Passive Vehicle Detection

Technologies that do not require any devices in the vehicle are the basis for most current vehicle detection systems. Passive approaches allow all vehicles in the vicinity of the sensor to be detected and monitored, but provide less information than will ultimately be available in the future.

Induction Loops: The most commonly used passive technology is the induction loop. This technique is extensively used for arterial controls and has a long history of successful field deployment. The advantages of induction loops are their well known performance characteristics, maturity, application flexibility, and multiple vendor sourcing. Over the years the manufacturers have enhanced and refined their equipment, providing numerous options and alternatives to meet a wide range of application needs. Pairs of loops can be used to measure speed and vehicle length for classification purposes. Some vendors have announced products that measure speed with a single loop, but field experience is limited. The disadvantages are the result of needing to embed the loops in the pavement surface, and the problems associated with pavement deterioration and freeze-thaw damage. Cutting of loop conductors during construction, and the need to reinstall loops when lane configurations are moved are also difficulties.

While induction loop detectors are often maligned because of the problems noted, they are currently the primary source of vehicle detection in most systems around the country. Studies in Los Angeles have shown that the accuracy of induction loop data with respect to vehicle counts (typically determined by video taping the traffic stream, and time-stamping and manually counting the vehicles on the video tape) is +0.6%. The immaturity of and/or lack of operational experience with many other technologies strongly encourages the use of loops as a key data source.

Magnetometers: Magnetometers, and the related micro-loop technology, are often suggested for deployment on bridges and other areas where loop installation in the existing pavement area could affect structural integrity. Magnetometers have had spotty operational success, and other technologies are being evaluated for these particular needs. However, the use of new digital processing technology has the potential to significantly improve the performance of magnetic detectors. A re-evaluation of their role will be appropriate after sufficient field experience is gathered. Preliminary results from IVHS Detection Technology project show that magnetometers have an accuracy in the +5% **range.**

Axle Counters: The requirement for 13 bin vehicle classification generates the need to count axles. The most commonly used technology is bending beam piezoelectric strips embedded in the roadway surface. These devices, working in conjunction with inductive loops, measure the vehicle length and speed, and count the axles. The vehicle length, combined with axle count, is used to classify the vehicle.

Radar: Radar detectors are in limited use in incident detection and freeway management projects. Most radar works on the doppler effect (measuring frequency shifts between the transmitted and received beam caused by the vehicle motion), and thus directly measures vehicle speed. Vehicle counts can be determined by accumulating each vehicle detected, but this approach cannot readily obtain lane occupancy and vehicle lengths. Similarly, detection of stopped vehicles, or very slowly moving vehicles, is difficult.

A second type of radar detector transmits a signal that is swept over a range of frequencies. This technique allows the range to the vehicle to be measured, and is thus able to function as a presence detector.

Radar detectors of the doppler and swept frequency variety require one antenna per lane, mounted on a structure or a sign bridge over the lane. If such a mounting arrangement is not available, the installed cost is significant when the sign bridge is included. The IVHS Detection Technology project early results show that these radar detectors have accuracies that range from +0.5% to +6%.

Another vendor has a product that can be mounted at the side of the road, and scan up to twelve lanes from one location. Since light poles and utility poles are often available, or can be readily installed, the device is more cost effective. The device can also detect vehicle presence, and is thus able to determine occupancy and existence of stopped vehicles. However, it does not measure speed directly, relying upon the standard “single loop” speed estimation equation based upon average vehicle length. The accuracy of this device, based upon the early results from the Detection Technology project, is in the +5% range.

The advantages of radar devices is the ease of use, requiring no cutting of pavement and disruption of traffic flow for installation or maintenance (if mounted on a structure or sign bridge where overhead access is possible). For the doppler units, direct speed measurement is a significant benefit. Similarly, when traffic lanes are relocated, radar antennas can be easily re-aimed. The disadvantages of radar are the requirement for a structure or sign bridge for overhead mounting, the limited field operational experience, the small number of vendors in the market, and the difficulties of accurately sensing lane occupancy and slow moving or stopped vehicles with the doppler units.

Radar detectors can be configured with two types of interfaces: RS-232 serial data and two pulse-type contacts. The serial data output provides the data (volume, speed, etc) as an ASCII data string. Modifications to this format to incorporate an error checking communications protocol will be required for stand-alone installation without a local field microcomputer. The dual pulse-type contact closures provide for emulation of a loop-pair speed trap. The first contact closure occurs when the vehicle enters the detection zone, and the second “dummy” closure is timed relative to the first closure to provide the correct travel time based upon a calibrated “loop spacing”.

Sonic: There are several techniques that have been explored utilizing sound. Some work as sonar devices, sending out sound waves and analyzing the returned echoes from the vehicles - much like the radar systems. The early results from the ultra-sonic unit included in the IVHS Detector Technology test shows an accuracy in the +2% range. Other sonic detectors passively “listen” to the noise generated by the vehicles, and analyze this noise energy to detect individual vehicles and resultant location and speeds. None of these devices are extensively used in the U.S., and thus field experience is limited.

Video *Image* Detection: Video Image Detection (VID) systems (sometimes referred to as machine vision systems) are comprised of fixed orientation CCTV cameras strategically located to provide views of specific areas or long sections of roadway, coupled with a computer that analyzes the video image in real time (30 times per second). This technology has been developed for various industrial, manufacturing, military and aerospace applications. It has been applied to traffic management in recent years, with growing success. Early systems were troubled by harsh environments, adverse and changeable lighting conditions, shadows, differing vehicle shapes, and sometimes difficult operating conditions. These difficulties have, for the most part, been solved by extensive field testing, actual deployment, more powerful computers, and increasingly sophisticated software.

Two fundamentally different strategies are used to analyze the video images: fixed analysis zones that detect vehicles moving through them, and vehicle identification and subsequent tracking. A third strategy, involving reading license plates "on-the-fly" is being used for toll violations and related applications, but is not directly applicable to this project. The technique utilizing fixed analysis zones, analogous to a "loop" in the video image, is the most stable and best tested approach. Equipment based on this approach can provide vehicle counts, lane occupancy, speeds, and lengths. Software in the VID processor collects the standard parametric information (volume, occupancy, and speed) and can also provide a variety of analysis and processing of this data, including statistics accumulation, data smoothing, and level of service calculations.

A key benefit of a VID system is its ability to monitor large areas of roadway from a single equipment location. Because the CCTV camera can be oriented to monitor a section of roadway (up to l/4 mile in length), and the entire image can be analyzed, significantly more roadway and numbers of vehicles can be monitored. The most promising usage of a VID system is detection of stopped or stalled vehicles (either in a travel lane, or on the shoulder), providing a direct detection of an incident. The monitoring of wide areas of roadway, coupled with individual vehicle detection, will provide significantly more information than existing point source (such as induction loop or radar) technologies.

While the promise of VID systems is significant, it is still a young technology that will evolve and grow for many years. There are operational problems under adverse lighting or storm conditions that will require more refinement. The early results from the Detector Technology project report accuracies ranging from =+0.3 % to +2.3 % , with accuracy decreasing under dark or adverse weather conditions.

Vehicle Detector Cost Comparisons

Two different categories of vehicle detectors are discussed above: those that are embedded in the road surface, such as induction loops, and those that are mounted overhead, such as a radar detector or a video image detector.

As discussed, embedding detectors in the roadway requires that the road surface be cut or drilled, and subjects the detector to failure due to pavement deterioration, etc. This can create ongoing maintenance problems, or poor detector reliability.

Detectors that are mounted above each lane, such as most radar detectors and ultrasonic detectors, require some form of support structure. A claimed advantage of this installation location is minimal traffic disruption during installation and maintenance. Mounting on an existing overcrossing is an option, but can create aesthetic concerns and often results in limited accessibility requiring that a traffic lane be closed to service the unit. The use of signal head mast arms is another possibility, but has the drawback of motion under high wind loading and the need to block traffic for installation and servicing. Sign bridges are a third possibility, and where they already exist are excellent choices, especially if they include a cat-walk so that the units can be installed and serviced without shutting down traffic. However, the installation of new sign bridges for the mounting of detectors is an expensive alternative.

In general terms, many of the overhead detectors cost between $750 and $1,000 per unit that monitors a single lane. Poles and mast arms cost about $200 per foot (with foundation and installation), resulting in a cost of roughly $2,400 for a 12-foot lane. This is about 2.5 times the cost of the detector. Sign bridges roughly cost $500 per foot (with foundation and installation), or $6,000 for a 12-foot lane. This is about six times the cost of the detector. This needs to be compared to the installed cost of induction loops of about $1,000.

Thus, overhead mounted detectors that must be positioned over each lane can be significantly more expensive than induction loops, when the cost of a mast arm and pole, or sign bridge must be included. Under those situations where an existing structure or sign bridge is available, they can be cost effective - but may still require traffic disruptions for installation and servicing.

Another category of overhead devices - side fired radar and video image detectors (VIDs) - can be mounted off the side of the road or on a pole in the median. This reduces the cost of mounting to roughly $5,000, and does not require stopping traffic for access to the unit. These devices also have the advantage of being able to monitor several lanes from a single unit, thus spreading the cost of the unit and the mounting pole across several lanes. A disadvantage of side mounting or an oblique camera view is the blockage of line of sight by larger vehicles (trucks) of smaller cars. This results in missed counts. With VIDs, the ability to discriminate between two closely following vehicles is a function of mounting height and angle of view. Increased height improves the discrimination ability, but results in a more costly pole and foundation. Another problem noted with VIDs is motion of the mounting pole under wind loading, or twisting of the pole due to differential solar heating. These conditions result in the camera field of view changing and "moving" the fixed analysis zones to another portion of the image.

For comparison purposes, a six lane cross section of freeway has been utilized. Five different equipment configurations have been evaluated:

- Induction Loops, with lead in wires saw-cut into pavement surface and processor cabinet on one shoulder;
- Side Fired Radar, with unit mounted on a pole located on one shoulder adjacent to the processor cabinet;
- Video Image Detector, with two cameras mounted on a pole in the median and the processor cabinet on one shoulder;
- Overhead Mounted Sensors on Mast Arm, with the pole in the median and the processor cabinet on one shoulder; and
- Overhead Mounted Sensors on Sign Bridge, with processor cabinet on one shoulder.

For all configurations, it is assumed that power and communications conduits are available at the location of the processor cabinet. With the exception of the video image detector, a Model 170 processor and cabinet is included. Conduit, cable, installation and testing costs are included for all cases. For the two configurations with median located poles (VID and Overhead Sensors on Mast Arm), costs for jacking conduit under three lanes are included.

Configuration	Per Lane	Six Lanes
Induction Loops	$3,400	$20,300
Side Fired Radar	$3,725	$22,350
Video Image Detector	$10,100	$60,600
Overhead Mounted Sensors on Mast Arm	$6,250	$37,500
Overhead Mounted Sensors on Sign Bridge	$13,250	$79,500

Active Vehicle Detection

Technologies that place electronics in the vehicle that interacts with the roadside infrastructure, and other vehicles in the immediate vicinity, is the direction that the automated guidance and highway systems is progressing. It will be at least two decades before these technologies become widespread, but devices in this category are being used for specific applications around the country.

Automatic Vehicle Identification: The recent conversion of many toll facilities to electronic toll tags, also referred to as automatic vehicle identification (AVI), creates a potential for vehicle detection and monitoring. By monitoring the movement of individual vehicles past various AVI antennas, the vehicles become active probes and link travel times can be determined. This technology is successful in areas where AVI tags are in use for toll roads, but is of limited applicability elsewhere. Since there are no toll facilities in the Louisville area, an existing population of AVI tags does not exist.

Another use of AVI technology is its use on transit vehicles to determine their location. The use of induction loops as the reading antenna has been successfully deployed in some areas. This usage of AVI has found a receptive audience since it allows more accurate tracking of bus fleets for control and dispatch.

Global Positioning Systems (GPS): GPS equipment is being used by various emergency (police, etc) and fleet (trucking) organizations to permit continuous tracking of vehicle locations. The costs per vehicle are still too high for widespread applicability, but the technique is very beneficial for those special cases where it can be justified. Accuracies range from a few hundred feet, to a few feet, depending upon the capabilities of the GPS receiver. The more accurate units are proportionally more expensive. GPS receivers as accessories for PCs are now available at prices of less than $1,000. As sales volumes increase, prices will continue to come down and hardware/software features will be added.

GPS receivers are an important component of vehicle navigation systems currently being tested. Vehicle location using this technology, coupled with a data channel linking the vehicle (police, fire, transit, etc) to the TOC is being evaluated as a component of incident response systems elsewhere in the U.S. The ability to locate emergency response vehicles, in real time on a status map, is a very useful tool in managing and coordinating incident response. After some initial operational experience is gained from the systems currently under development, the effectiveness and costs can be evaluated for possible usage in Louisville.

Automatic Vehicle Location: A variation on the GPS strategy is the use of location beacons that can be monitored by a vehicle, such as a bus. Through the use of an on-board computer, monitoring of the vehicle's movement with a electronic odometer, and known information about a route to be followed, the location of the vehicle can be estimated. The location beacon allows the strategy to be refined by providing "check-points" that permit the on-board computer to update and correct its estimates of location.

The periodic transmission of vehicle location to a central computer allows a central dispatcher to track the vehicle. This tracking can be matched to a bus schedule, for example, and alert the driver and the dispatcher if the bus is ahead of or behind schedule. This automated vehicle monitoring can be input to the traffic management system to serve as active probes in the vehicle stream, similar to the AVI system discussed above. The use of buses as probes must take into account the start/stop nature of transit vehicles when estimating the flow of traffic. The integration of this tracking with voice communications to the bus driver is a very useful tool in locating incidents, and determining their nature and severity. The Transit Authority of River City (TARC) is currently implementing a vehicle location system of this type.

DETECTOR DATA PROCESSING

The processing of the data collected from the vehicle detection system requires that a balance be maintained between locality of data availability, processing capability, communications circuit loading, and access to the data for analysis and presentation. Three options are typically considered:

- Transmit the data to a central location every second.

- Aggregate the data in the field for a specified time period (typically 20 sec, 30 sec, or 1 minute), and transmit the aggregated data to the central location at the end of the collection interval.

- Aggregate the data over a collection interval (20 sec, 30 sec, or 1 minute), store this data in the field for an extended time period (up to several hours), and transmit it to the central location when required. The requirement for the data can be based upon an "event" occurring in the field, such as the detection of an incident; or when requested by the central system.

The first option requires relatively few bits to transmit vehicle counts because of the limited number of vehicles passing by a detector in one second. Lane occupancy and vehicle speeds require about 10 bits per data item, in order to maintain accuracy. This combination of number of bits to transmit, and the one second transmission frequency places a heavy burden on the communications network (typically 1,200 bps). It also requires a larger central computer system to handle the data volumes and the data updates every second.

The one case where second by second updates are required is the monitoring of an arterial intersection controller, or an individual freeway monitoring computer. Since this monitoring typically is required for only a few (less than 10) such controllers simultaneously, the overall system design need not provide the capability for every controller to communicate with the TOC every second.

Option two utilizes the power and processing capabilities of currently available microprocessors. As the processors that are deployed in field locations become more powerful and less expensive, distribution of the data processing is advantageous. This lessens the load on the communications network, and reduces the need for a larger central computer. The dynamics of traffic flow, and the rate of update of status maps and displays at the TOC establish the frequency of data transmission from the field devices. Operational experience show that updates every minute are not frequent enough, and updates every 10 seconds appear to be too frequent. This range has resulted in a 20- or 30-second time interval being utilized by most operational systems - with 20 seconds being preferred.

With this option, the field processor collects the data for the selected time interval, and stores it in an intermediate data buffer until polled by the central computer at the TOC. There are numerous operational results, levels of service and summaries that can be calculated from the collected data. Since these calculations are equally simple to perform at either the field processor or the central computer, no advantage is gained by transmitting these derived values to the central system. They can be computed on an as-needed basis at the TOC (or other location) from the "raw" field data "less expensively" that transmitting them. If they are needed at the field processor, for example by a technician reviewing the operation of the field equipment, they can be calculated at that time in the field. This requires that the field processor have sufficient memory to store several hours (or days) worth of data. Computer memory in the Mbyte range is now very inexpensive, allowing this strategy to be implemented.

The data collected from an induction loop in a 20-second period can be represented in less than three bytes of data, and the speed/length/classification counts obtained from a speed loop pair requires less than six bytes of data. Thus, with six main-line lanes, one entrance ramp and one exit ramp being monitored, six speed pairs and four individual loops would be utilized. This results in about 84 bytes of data, plus overhead of about 20 bytes, being transmitted between the central computer and the field controller each 20-second period.

The case noted above where second by second monitoring of a controller is required must be included in the design of a periodic data collection/polling system. Since 20-second data collection and the second by second reporting are both equally important, the communications system must be designed to permit the 20-second data collection to be interleaved with second by second reporting. This interleaving must occur in a manner that does not exceed the delay requirements of either data stream, and fits within the available bandwidth of the communications channel.

The third option is useful when routine, periodic refreshing of status maps or data displays is not required. A data collection example would be the transmittal of stored volume/occupancy data from the second loop of a speed loop pair only on as requested basis. Another example would be an incident detection algorithm running in the field microprocessor based upon variations in speed of individual vehicles - detail data which is lost when the speeds are averaged over a 20-second period. Error reporting also falls into this category, since errors are infrequent events and need to be reported only when they occur.

The goal of most traffic monitoring and management systems is to reflect the "real-time" status of the roadway at the TOC, or other centralized location. This requires that data be transmitted from the field to the central computer on a regular basis. However, as noted in the examples above, there are categories of information that are infrequent (errors or detected incidents), or stored data that is needed only on a "demand" basis (the data from second loop of a pair), or data that is available in the field processor but normally not used at the central computer (standard deviation of speed). All of these situations require that the communications protocol and data formats be flexible enough to allow notification about or requesting of this occasional data.

CLOSED CIRCUIT TELEVISION

Closed circuit television (CCTV) provides the eyes for the operator at the traffic operations center. Operational experience shows that constant monitoring of CCTV images by operators is not effective, as the operator soon becomes "numbed" by the constant repetition of vehicles moving across the screen. The primary role of CCTV is to verify a reported incident, to evaluate its severity, and determine the appropriate response vehicles and personnel to dispatch to the incident scene.

The biggest problem to overcome with CCTV is the transmission of the image from the camera location to the control center. Video requires a communications channel that is equivalent to more than 2,000 voice grade audio channels. Thus, most efforts in optimizing CCTV systems are directed toward reducing the bandwidth of the CCTV communications channel. These efforts range from not updating the image in real-time (every 1/30 sec), to digitally compressing the image, through analyzing the image and transmitting only the moving elements of the image.

The baseline for CCTV transmission is "broadcast" quality, full-motion, real-time images. To date, this is most often implemented via a fiber optics based communications system, with full bandwidth channels allocated for CCTV images. With the tremendous bandwidth available on a fiber optics system, this direct approach is the least costly and provides the best performance. When this is not cost effective, alternative solutions must be utilized.

Camera Type (Color vs. Black-and-White): Color images provide the greatest amount of visual information, and are the preferred choice of most traffic operations centers. However, color CCTV cameras rapidly lose their sensitivity under nighttime, or other dim, lighting conditions. Black-and-white cameras, on the other hand, are available that will produce usable images even when it is too dark for a person to see. Some vendors have solved this dilemma by packaging both a color camera and a black-and-white camera in the same housing. This of course increases the price of the assembly, but the added cost may be acceptable in some locations. Actual field testing should be performed, or verification of performance by another traffic operations center, before committing to a specific equipment selection. Typical cost of color camera, with field controller and cabinet, pan/tilt unit, pole and foundation, with installation and testing is $20,000.

Pan/Tilt/Zoom/Focus Control: The CCTV camera in the field must be moveable (left and right, and up and down) in order to permit it to monitor the greatest possible area. Similarly, a zoom lens to allow viewing of vehicles at varying distances and associated focus control, is required. These functions must be controllable by all operators who have access to the CCTV images. This functionality is implemented by placing a microcomputer at each CCTV location that receives commands from the traffic operator, and turns on and off the appropriate motor in the pan/tilt unit or the motorized lens.

Each CCTV system vendor has its own proprietary system for this type of control. As systems grow and expand over time, control compatibility must be maintained so that the operator is not faced with several different camera control systems. The needs for the control system, both initial and long-term, must be addressed during the system architecture design, considering the growth requirements and future needs.

Digital vs. Analog Transmission: The technology used to date for most long haul, “broadcast quality” CCTV systems has been analog transmission. Within the past five years, significant progress has been made in the development of cost-effective digital transmission equipment. Once video is converted to a digital format, it can be transmitted over a SONET communications system with no further conversion and with no degradation of image quality. Additionally, digital video switches are smaller, and lower priced than analog switches.

Another benefit to digital video is the ability to compress the video image, and thus utilize less bandwidth on the data communications channel. Typical compression ratios are 40: 1. The cost of compression/decompression (codec) equipment is currently about $20,000 per unit, but new products are being discussed which may bring the price down into the $5,000 range. Given normal price/performance curves in the digital electronics industry, this price drop will probably require about 3 years. The development of digital video transmission discussed above is expected to meet the anticipated schedule of the I-65 freeway incident management system. However, if price/performance ratio for digital systems does not progress as rapidly as desired, an analog system will serve as an acceptable alternative.

Fiber vs. Coaxial Transmission: The use of fiber optics for transmission of video has almost completely replaced the use of coaxial cable, except for very short runs of less than 500 feet. Fiber optic transceivers are now available with ranges up to 5 miles for multi-mode fiber, and 20 miles for single-mode fiber. These transceivers range from less than $300 for short range units to $2,000 for long range devices.

Centralized Control/Geographically Distributed Control: The need for centralized control (at the TOC) of the CCTV cameras is previously discussed. An effective and needed strategy in modern incident/traffic management systems is distributing video images, and associated control of the CCTV system to several locations for joint, coordinated response to an incident. This requires that the CCTV control, and video transmission system, be designed with this requirement in mind.

Video Switch (Camera to Monitor ratio): A key component of the CCTV system is the video switch that allows any CCTV camera to be viewed on any monitor, at any location that has access to the CCTV system. A variety of switch architectures are available, from fully centralized to fully distributed. Each has its own advantages and disadvantages, and associated costs. Most CCTV systems have more cameras than monitors, with typical ratios being in the 3:1 to 10:1 range. The cost of video switches is a function of the number of switching points, which is the product of the number of camera inputs and monitor outputs. Thus, prices can increase exponentially as the size of the switch grows. For a relatively small switch (30 camera inputs and 10 monitor outputs) the installed cost is about $20,000. Doubling the size of the switch to 60 camera inputs and 20 monitor outputs results in the cost increasing to about $75,000. Cost of video monitors, interconnection to the video transmission system and monitors, operator controls and system integration is in addition to the cost of the basic switch.

Large Screen Projection: A large video screen (3' x 4', or larger) is often included in traffic operations centers. The ability to project either an enlarged video image, or an enlarged computer generated graphic is very useful for decision support during incident response or for public relations during tours or demonstrations. Operators in TOCs with large screens report that they seldom use these enlarged images during normal operations.

Two fundamental technologies are used: video projection, and video wall. Video projection utilizes either a cathode ray tube (CRT) or a liquid crystal display (LCD) system to optically enlarge the image and display it on a screen (front or rear projection). A video wall combines several moderate sized (21 inch typical) video monitors into an array. This array is often three monitors high and four monitors across. Electronic circuitry divides the original image into 12 parts (for a 3 x 4 array) and displays each sub-image on a separate CRT. Current cost for large screen projectors is in the $35,000 range.

WEATHER MONITORING

Weather monitoring systems are finding increasing use in locations where localized temperature or precipitation conditions can disrupt traffic, or require roadway maintenance activities. The most common use is for monitoring visibility and road surface freezing conditions for traveller information, or for dispatch and management of snow and ice removal crews. The responsibility of the National Weather Service is for general and severe weather forecasting. This role often does not provide the detail, up-to-the minute data needed to optimize the management of roadways due to local conditions.

Currently available technology can monitor pavement surface conditions, especially temperature which can be as much as 7° C warmer than the air temperature at the start of a storm, and can lag several hours behind the temperature of the air as it cools. An inverse situation is surface radiational cooling on a clear night, resulting in a roadway surface that is below freezing and icing from water vapor in the air.

The first situation, when managed based upon roadway surface conditions can result in several hours delay before ice control chemicals are required. This delay reduces labor costs and materials costs for effective ice management. Some agencies have reported savings of more than $20,000 in a single storm.

The second situation, where unexpected icing conditions develop can be detected and alarmed by a weather monitoring system. This alarming can be used to dispatch sanding crews in a timely manner to reduce the hazard and the resulting accidents.

These weather monitoring systems can provide a variety of data inputs: including roadway surface temperature, surface condition (dry, wet, ice, dew, frost), chemical concentration on roadway surface, sub-surface temperature, air temperature, relative humidity and dew point, wind speed and direction, precipitation rate and type, and visibility. This data, when monitored locally and tracked over time, provides additional information for effective management and decision making. Specialized analysis of the data, when combined with wider area weather information, can be provided by a service organization staffed by professional meteorologists. This additional analysis supplies forecasts and interpretations of conditions that can enhance the management of the area roadways. Nearby states that have installed this type of equipment include: Indiana, Illinois, Ohio, and Tennessee. Many agencies on the East Coast and northern mid-west utilize weather monitoring systems.

The system consists of surface sensors, atmospheric sensors and a field microprocessor. Each field site costs about $25,000 to $30,000. A central computer, together with communication ports and modems, collects the data from each field site on a regular basis. A software package in the central computer stores and analyzes the data, and presents it in graphical and tabular form. The central hardware/software package costs about $30,000.

VARIABLE MESSAGE SIGNS

Variable Message Signs (VMS), either fixed or portable, are widely used to provide motorist information during an incident. The ability to quickly alert motorists of a problem ahead, and provide for diversion to an alternate route, is a successful strategy for minimizing the impact of an incident.

A VMS consists of a matrix of dots, each of which can be individually controlled. The minimum group of dots for a single character is five dots horizontally and seven dots vertically. Larger “character cells” are often implemented for improved character resolution, the use of lower case letters, and “double stroke” characters. Since individual characters on a VMS are composed of discrete dots, the “sharpness” of a character is controlled by the number of dots per character. The tradeoff is cost, with cost of the sign being proportional to the number of dots on its surface. The human eye fuses together the adjacent dots in the character pattern, and recognizes the character as a whole. In general, the legibility of 5x7 character cell VMSs is very acceptable, if only upper case letters are used, which is typical for roadway applications. When lower case is required, or other effects are needed, larger character cells, and proportionally more expensive signs, are utilized.

If the VMS is intended for text messages only, adjacent "character cells" are separated by a blank space to minimize the cost of the sign. An alternative approach is the "continuous matrix" sign, in which the separating blank space is deleted, resulting in all locations on the surface of the sign being controllable. This permits moving text, "exploding" and "collapsing" images, roller blind, horizontal shutter, etc. type of special effects to be implemented. These special effects are more commonly used in commercial displays than in roadway applications. The use of a proportional font for improved readability or graphics is a common use of continuous matrix signs on a roadway.

Because a VMS can display a wide variety of characters in each character cell, dynamic messages can be created by manipulating the timing of the display of individual characters, or groups of characters. Simple effects that are quite effective for roadways include blinking text, moving arrows, and the cyclic display of a sequence of messages with delays between them. An example of the latter is displaying a repeating series of safety messages, such as "BUCKLE UP," "DRIVE 55 FOR SAFETY," and "USE YOUR SEATBELT." Message complexity, information acceptance rate, and driver attention span all must be considered when utilizing these features on high speed roads.

Two fundamental technologies, light reflectance and light emission, are used to form the individual dots that create the letters of the message.

Light Reflective Signs

Light reflecting VMSs consist typically of a matrix of mechanically changed dots. The individual dot can be a flat disk that is black on one side, and colored on the other, or a ball or cube that has color on one half, or a split flap that exposes a colored surface when opened. Other implementations consist of a multi-part flap that some vendors have utilized to implement a "white" character for daytime usage, and a "fluorescent color" character for improved visibility at night. This technique has been extended by one vendor to allow display of six different colors for each pixel. A variety of techniques have been used to improve the visibility of these signs, including internal illumination and retroreflective surfaces. Because the dots are mechanically moved, a finite amount of time is required to change the message displayed on the sign. Different vendor's implementations result in a range of timing characteristics. On the slow end of the spectrum, rates of 30 characters per second are typical. At this speed, a sign with three rows of 22 characters per row will require over two seconds to change its message. Faster character write rates are available, but tradeoffs of power consumption, dot inertia, overshoot, and flutter all enter into the dynamics of the implementation.

To provide stability during periods of power outage so that dots do not randomly change position and display "garbage" on the sign face, and to reduce power consumption, some method of latching the dots into a fixed position is normally used. A common technique is magnetic, where a small fixed magnet is attached to the shaft on which the dot rotates. The dot is changed from its “dark” state to its “bright” state with a pulse of an electromagnet, thereafter remaining stable with no power input required. This has the advantage that a message that was displayed prior to a power failure will remain on the sign face.

These signs have a proven field track record, with a generally high reliability rate. Individual dots are rated in the range of 100 million operations. However, it is not uncommon to find individual dots stuck, either “dark” or “bright”, as a sign ages. The signs are fabricated for easy repair, with each character cell being quickly replaceable, and individual dots being repairable. The technology is easily scaleable, with character sizes ranging from 2 inches to 18 inches in height. A wide range of colors can be used on the “bright” side of the dot, with white or yellow being most common, but green, red, orange, gold, and others being available. Because of the mechanical nature of this technology, a weatherproof enclosure is required. Cost of these signs is in the medium to expensive range, depending upon size, mounting, enclosures, and various options. For many agencies, these signs have been the “mainstay” of their VMS implementations.

By mechanically rotating the disk, ball, or flap with different colors on the surfaces, the dots on the surface of the sign form letters. The key advantage of this type of sign is the maturity of technology, and the long experience of their usage. Another advantage is the continued operation of the sign during a power outage, since the dots are bi-stable — requiring power to change their state, but not to maintain them in a particular state. The disadvantages include limited visibility under some lighting conditions, fading of color contrast over time, and mechanical failures resulting in a “stuck dot.”

Costs of these signs is a direct function of the number of characters on the sign face, and the attention to detail and quality by the manufacturer. Since this type of sign is electro-mechanical, operational experience and product refinement based on many years of development have an impact on long-term reliability. Large signs (3 rows by 20 characters/row) range in cost from $50,000 to $90,000, including installation and commissioning. Small signs (3 rows by 8 characters/row) cost $25,000 to $50,000. The cost of the support structure (sign bridge, attachment to overpass, or roadside poles) is in addition to the basic sign cost.

A related type of sign is the rotating drum sign, where several faces of a rotating drum (or several drums) can be used to display one of several messages. These signs can be configured with the same size, shape, and letter fonts as traditional static signs. Further advantages are their lower cost when compared to a “dot matrix” sign, and mechanical simplicity resulting in higher reliability. Their prime disadvantage is the limited number of messages that can be displayed on a single sign. The drum sign has applications where a fixed message (such as LANE OPEN/LANE CLOSED) has to be displayed for portions of a day. Their use for incident response is limited.

Light Emitting

The use of an active light source at each dot (or pixel) of a VMS produces a light emitting sign. The original light emitting sign is the incandescent bulb matrix. This type of sign provides good visibility, and is currently used in commercial applications. However, it has fallen into disfavor for roadway applications due to the low reliability and high maintenance costs from bulbs burning out. Another major problem is heat as a result of the high bulb wattage, and the resultant power consumption. Some agencies in warm climates have found that they have to limit the number of bulbs that are simultaneously ON due to heat rise in the sign enclosure. In general, these signs are not favored because of these limitations.

Current technology developments utilizing “solid state” lamps over the past several years have produced signs with high brightness, simple control, and long life. The light source in these signs is the light emitting diode (LED). Until recently, the brightness of the LED has not been fully adequate for bright daylight conditions. In particular, the “amber” LED, which is preferred for roadway usage, has been difficult to manufacture with the desired characteristics. Early LEDs suffered from variability in light output between “identical” LEDs, and aging effects which reduced the brightness (often non-uniformly) over time. However, about three years ago these problems appear to have been solved, and the LED sign is finding acceptance in the field with many major manufacturers fabricating these signs.

A typical implementation utilizes a group of LEDs (on the order of 15) to form each individual pixel. This increases the brightness of each pixel, and averages any small differences between adjacent LEDs. These signs have a very fast turn on and turn off time, removing the problems noted above with the rotating disk type signs. LEDs, because of the nature of the physics of the semiconductor junction and the wavelength of emitted photons, have a limited range of colors. Red is the most common color, but yellow is preferred for most roadway signage applications. Green is also commonly available. Combinations of different colored LEDs are being used to implement “colored” signs. The small size of the LED, coupled with computer type integrated circuits, can produce displays with large numbers of individually controllable dots for special effect applications. The long life of the LED, combined with the inherent simplicity of the design concept, should result in very good reliability. Actual field experience, as these signs are deployed in large numbers, will have to be gathered to verify this expectation. Cost of these signs is moderately expensive, but that should change as the usage increases.

Enhanced visibility is the key advantage of light emitting signs. The ability to mix various color light sources to produce differently colored messages is also useful. The biggest disadvantage of these signs is their requirement for continuous power, making them non-operable during power failures. If power failures are common, and the sign is critical to continued operations, some sort of back-up power is required.

LEDs have had some problems due to loss of light output intensity due to the aging of the light emitting active elements. Intensity reductions on the order of 50% have been observed after 30,000 hours of operation. A side-effect of this problem has been brightness differentials as a result of differing power-on times. This results in variations between different dots on the sign.

Newer generations of LEDs appear to have solved these problems, with preliminary reports indicating either no intensity loss, or even a slight gain. This is based on initial testing, with long-term field results not yet available. Another benefit of these newer LEDs is their increased intensity, allowing a sign to be fabricated with fewer LEDs per pixel (resulting in a lower fabrication cost), or a brighter sign with the same number of LEDs, or the ability to operate the LEDs at lower power (prolonging their life and reducing the aging effects).

Costs of LED signs is controlled by the size of the sign (number of characters on the sign face), the quality and reliability focus of the manufacturer, and the type of LED used. The newer, high-output amber LEDs are more expensive than older devices because of limited manufacturing yield and the need for the supplier to recover development costs. As with all semiconductor devices, component prices will decline fairly rapidly - especially as sales volumes increase. Large signs (3 rows by 20 characters/row) range in cost from $60,000 to $130,000, including installation and commissioning. Small signs (3 rows by 8 characters/row) cost $40,000 to $60,000. Cost of the support structure (sign bridge, attachment to overpass, or roadside poles) is in addition to the basic sign cost.

Hybrid

The combination of a rotating disk or shutter in front of a light source produces a hybrid of mechanical motion and light emission. If the rotating disk is colored on one side, the light source "enhances" the message on the sign, providing additional visibility and "punch" for longer distance viewing. Some vendors consider this an enhancement of the basic rotating disk/shutter sign, while others explain their product as a totally different technology.

The LED is often used as the light source, with the LED being mounted behind the disk, and the disk serving as a shutter to permit the LED to be seen when the disk in the "bright" position, and masking the LED when the disk is in the "dark" position. One implementation mounts the LED off center, with a hole through the disk. When the "bright" side of the disk is visible, the hole is positioned over the LED. When the disk is rotated so that the "dark" side is exposed, the hole and the LED no longer coincide, and the LED is masked. Different vendors implement this same basic idea with a range of schemes, all effectively performing the same task.

A variation of this approach utilizes digital control technology that is connected to the circuit that controls the disk, and turns off the LED at each pixel when the "dark" side of the disk is exposed. This technique requires a location within each pixel that is constantly visible, and works well with circular dots where the LEDs can be located in a "comer" of the pixel. However, with split flap pixels that are square or rectangular in shape, the locations for mounting the LEDs are limited.

The approach of combining a light source with a light reflecting sign is an effective manner for increasing the visibility of the basic VMS, producing a good combination of daytime and nighttime usage. The prime reliability concerns are those of the basic sign. Cost is greater than that of the basic sign, and the performance enhancement must be considered within the constraints of the project.

A matrix of shuttered pixels, with each pixel containing a fiber optic bundle that is illuminated by a high intensity light source is another combination used by some vendors. The concept utilized with this design is that of a light source for several characters (on the order of three or more), and bundles of optical fibers to "pipe" the light to each individual dot on the sign face. One configuration utilizes a rotating disk as the shutter. In another configuration, the shutter is assembled with its rotational shaft perpendicular to the sign face. This shutter functions in a manner similar to that of a camera, alternately blocking or uncovering the light source. The mechanical orientation of the shutter, and its motion, seem to result in enhanced reliability.

The light source is a high intensity light bulb, similar to that used in a slide projector. The brightness of each individual dot is several times brighter than that obtainable with the hybrid LED sign. A useful design "trick" is to utilize two separate bulbs for each fiber bundle, with an automatic switch over circuit when a bulb fails. Monitoring the current flow of the small number of bulbs involved in this design is convenient, resulting in the ability to report a bulb failure to the central control station. The second bulb can also be used to produce an "overbright" condition for poor visibility conditions, such as fog. Another convenient feature utilizes a motor driven colored filter between the bulb and the fiber optic bundle to produce different colored characters on the sign face.

This type of sign has carried a higher price tag, making it the "cadillac" of VMS applications. The prime selling feature of these signs has been their brightness and resulting high visibility. Some vendors emphasize the reliability of their signs, which may be more a result of high 'quality manufacturing and engineering, than the fundamental technology. Competition, other market forces, manufacturing efficiencies, and related factors may eventually push the price down to being more competitive with other technologies. As more of these signs are installed and field experience gained, their relative merits will be more sharply focussed.

The combination of devices (light source and mechanical shutters) used to create a hybrid sign increases the cost about 20% over either light reflective, or a light emitting sign. However, the increased visibility is a key benefit that is often required.

The cost of hybrid signs is also the result of the size of the sign (number of characters on the sign face), and the approach taken by the manufacturer. The "flip-disk" signs, to which LEDs or fiber-optic light sources are added as an enhancement cost 15-20% more than the basic sign. Thus, for a large sign (3 rows by 20 characters), the cost will be in the $60,000 to $105,000 range. And a small sign (3 rows by 8 characters) will cost $30,000 to $60,000. The fiber optic sign that utilizes shuttered pixels is primarily available in a 3 row by 18 character configuration, and costs about $135,000, including installation and commissioning. The cost of the support structure (sign bridge, attachment to overpass, or roadside poles) is in addition to the basic sign cost.

VMS Control Systems

As the number of individually controllable elements on the sign face increases, the complexity of the control requirements increases. For all but the simplest rotating drum signs with just a few messages, some sort of computer based control is required. The manufacturers have selected a variety of microcomputers to meet this need. A few manufacturers have selected the Model 170 intersection controller as the microcomputer, which has the advantage of utilizing a standard item of hardware that is familiar to highway agencies. In other cases, the vendor has developed a special purpose microcomputer for controlling the specific sign they manufacture. In all cases though, a unique software package has been developed for each implementation.

Similarly, the command set used for communication between these signs and a control location is unique to each vendor's system. This command set is called the "communications protocol."

For an agency getting started with VMSs, a fully packaged system from a single supplier is simpler because the vendor can be assigned total responsibility for the system. But the "proprietary" nature of each vendor's implementation (because standards have not yet been defined) creates difficulties when trying to integrate equipment from several vendors into an overall system. An agency can easily get "locked into" a single supplier, when there are superior or more cost-effective products available. Or the agency can suffer from poor support, or a product being "orphaned" when a newer model is introduced or a company is bought out.

In any application of VMSs where more than a "few" different messages are to be displayed, some form of central control and operator interface is required. The "central" control computer supplied by the vendor for remote access to and monitoring of the signs is usually a PC, but often with vendor specific hardware enhancements such as unique serial communications boards. The software that runs on the PC is unique to each manufacturer's implementation, and ranges from "convenient" to "obtuse" in its user interface. Prices for the central system range from little more than the cost of the PC itself, to many times that, depending upon the features, the total system size, and the vendor's perception of the value of the central control system. The complexity of this software must not be underestimated. There are a great many features, interdependencies, database management issues, and operating subtleties to be handled, all of which contribute to the implementation difficulty and resultant cost.

The challenges associated with the control system can be addressed by carefully understanding the operational needs of the system, considering the growth requirements and future needs. In all cases, the vendor must be required to supply full documentation of all system components. The details of the communications protocol are especially important, so that existing signs can be integrated into a larger system when the agency's needs evolve. Another option that will be available in the near future is the specification of the National Transportation Controller/IVHS Protocol (NTCIP) . This protocol is currently under development by NEMA/FHWA for NEMA/170 controllers, and will be extended to VMSs after the initial traffic controller work is completed. Selection of a VMS on the basis of ease of integration into a future larger system will usually be beneficial as the overall scope of this type of traffic information system increases.